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DEVELOPMENT OF NEW GENERATION OF MULTIBODY SYSTEM COMPUTER SOFTWARE

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
12 APR 2012	**Briefing Charts**	**05-03-2012 to 08-04-2012**

4. TITLE AND SUBTITLE	
DEVELOPMENT OF NEW GENERATION OF MULTIBODY SYSTEM COMPUTER SOFTWARE	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Ahmed Shabana; Paramsothy Jayakumar; Michael Letherwood**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Illinois at Chicago,1200 W. Harrison,Chicago,IL,60607**	8. PERFORMING ORGANIZATION REPORT NUMBER **; #23794**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000**	10. SPONSOR/MONITOR'S ACRONYM(S) **TARDEC**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **#23794**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

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15. SUBJECT TERMS

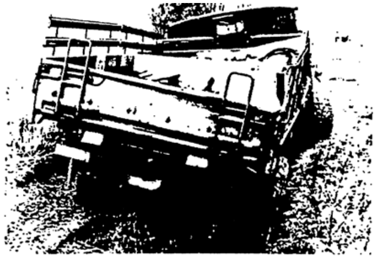
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Public Release**	**12**	

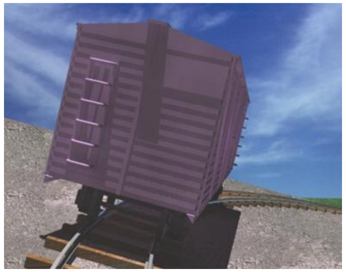
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

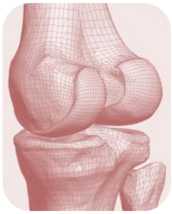
Contents

Multibody Systems (MBS) and Vehicle Mobility (VM)

1. MBS simulation tools are required for the analysis, design, performance evaluation, and virtual prototyping of vehicle systems.
2. MBS dynamics is, therefore, a critical research and development area for automotive, machine, aerospace, and rail industries.
3. The accuracy of the computer models depends on the level of details that can be captured by the MBS simulation tool.
4. MBS software technology (formulation) is 30 year old technology. This technology cannot capture details of modern vehicle system models.
5. There are serious limitations: (1) Development of general deformation models; (2) Development of analysis models with accurate geometry.
6. These limitations will require the development of new codes that have different structures.

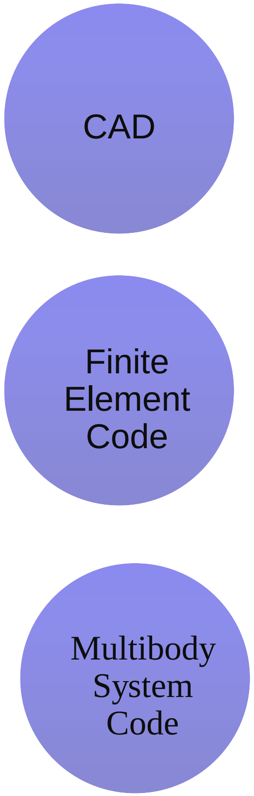






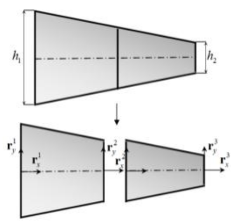
Challenges of MBS Simulations

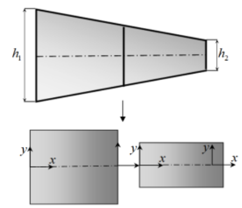
1. Existing flexible MBS software technology requires the use of three separate codes and three separate licenses.
2. The first is a CAD system for the geometric and solid modeling (AuoCAD, ProEngineer).
3. The second is finite element (FE) code for determining the inertia constants and stiffness coefficients that enter into the nonlinear MBS equations (ANSYS, NASTRAN).
4. The third is MBS code for performing the simulation (ADAMS, DADS, SIMPAK).
5. The integration of three different computer codes and having three different licenses is a problem for the industry.
6. For example, conversion of solid models to an FE mesh is very costly. The cost to the U.S. automotive industry alone is more than $600 m/year.

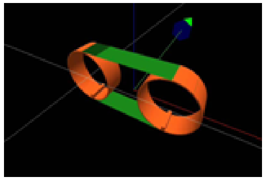


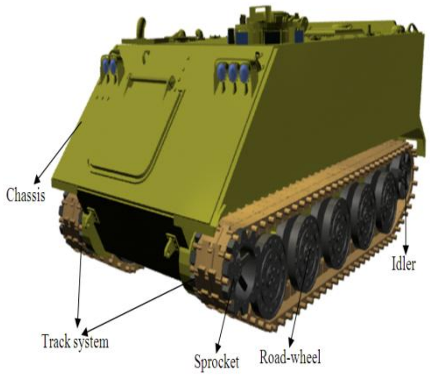
Limitations of Existing MBS Software Technology

1. The conversion of CAD models to analysis meshes leads to geometry distortion (structural finite elements).
2. MBS simulation codes are not designed to solve FE large deformation problems.
3. They do not allow for the use of general constitutive equations with structural finite elements such as beams, plates and shells.
4. Existing MBS codes have a structure that makes the simulation of practical systems very costly or impossible.
5. Significant modes of deformations cannot be captured using existing MBS and FE software technology.



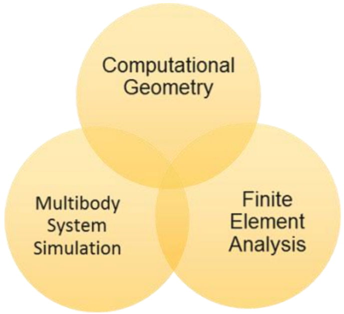






New MBS Software Technology

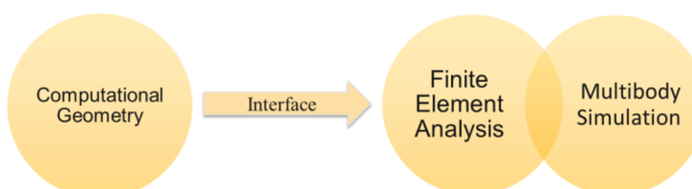
1. Implement a unified computational framework for geometry (CAD), finite element (FE), and multibody system (MBS).
2. Allow for efficient and systematic conversion of CAD models to FE/MBS meshes without any geometry distortion.
3. Allow for the use of general continuum based FE deformation models that cannot be systematically solved using existing MBS software technology.
4. The new generation of MBS codes will be based on new approaches and algorithms.
5. These new codes which are currently under development, will be used for developing the CAD geometry as well as small and large deformation analyses (one license instead of three).
6. These codes will allow developing continuum-based models for flexible link chains, soil, tires, belts, cables, ligaments, muscles, soft tissues, etc.



Approaches and Features

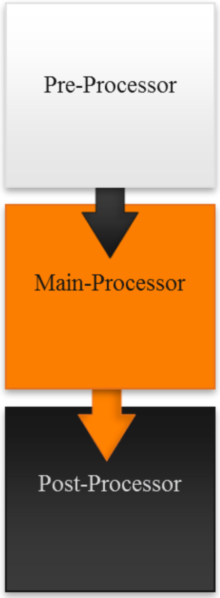
1. Integration of CG/FE/MBS algorithms can be accomplished using the new absolute nodal coordinate formulation (ANCF).
2. ANCF finite elements have unique features including constant mass matrix, zero Coriolis and centrifugal forces, unique rotation field, general continuum and material models.
3. Solid models can be converted to ANCF meshes using a linear mapping (no geometry distortion).
4. The new software will maintain the desirable features of existing MBS software including efficient implementation of the floating frame of reference formulation (FFR).
5. ANCF meshes with constant inertia matrix and linear connectivity conditions will lead to an optimum sparse matrix structure.
6. The numerical algorithms will ensure that the algebraic constraint equations are satisfied at the position, velocity, and acceleration levels.

$$\begin{bmatrix} \mathbf{P}_0 \\ \mathbf{P}_1 \\ \mathbf{P}_2 \\ \mathbf{P}_3 \end{bmatrix} = \begin{bmatrix} \mathbf{I} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{I} & \frac{l}{3}\mathbf{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I} & -\frac{l}{3}\mathbf{I} \\ \mathbf{0} & \mathbf{0} & \mathbf{I} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \mathbf{r}^A \\ \mathbf{r}_x^A \\ \mathbf{r}^B \\ \mathbf{r}_x^B \end{bmatrix}$$



Structure of MBS Software (Preprocessor)

1. The new software will have a pre-processor, a main processor, and a post-processor.
2. The pre-processor will have three modules: Geometry Module, FFR Module, and the ANCF Module.
3. The Geometry Module will serve as an interface between existing CAD systems and the new software.
4. The FFR Module will be a comprehensive preprocessor for the small deformation analysis with an extensive library of conventional finite elements.
5. The ANCF Module will have an extensive library of ANCF finite elements. It will also develop the Cholesky transformation that leads to identity mass matrix.
6. The preprocessor will produce files that contain data that are required for the solution of the flexible MBS equations.
7. Using the FFR module, there will be no need for FE license. Further development of the FE-based geometry module will also eliminate the need for a CAD license.

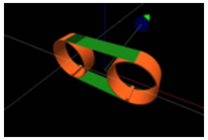


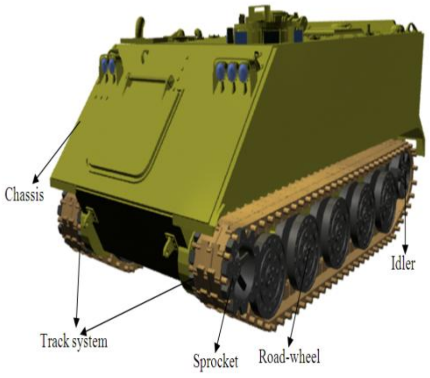
Structure of MBS Software (Main Processor)

- The main processor will allow for systematic and efficient modeling of rigid, flexible, and very flexible bodies in MBS applications.
- It will be based on a sparse matrix structure.
- It will allow for modeling large deformations and the use of general continuum mechanics approach and general material models.
- It will capture displacement modes that cannot be captured using existing MBS codes.
- It will take advantage of the FE ANCF meshes that have linear joint formulations and constant mass matrix.
- Explicit and implicit numerical integration methods will be implemented.
- The algorithms used will ensure that the constraint equations are satisfied at the position, velocity, and acceleration levels.

$$\mathbf{q} = \begin{bmatrix} \mathbf{q}_r^T & \mathbf{q}_f^T & \mathbf{p}^T & \mathbf{s}^T \end{bmatrix}^T$$

$$\begin{bmatrix} \mathbf{M}_{rr} & \mathbf{M}_{rf} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{\mathbf{q}_r}^T \\ \mathbf{M}_{fr} & \mathbf{M}_{ff} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{\mathbf{q}_f}^T \\ \mathbf{0} & \mathbf{0} & \mathbf{I} & \mathbf{0} & \mathbf{C}_{\mathbf{P}}^T \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{\mathbf{q}_s}^T \\ \mathbf{C}_{\mathbf{q}_r} & \mathbf{C}_{\mathbf{q}_f} & \mathbf{C}_{\mathbf{q}_a} & \mathbf{C}_{\mathbf{q}_s} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}}_r \\ \ddot{\mathbf{q}}_f \\ \ddot{\mathbf{p}} \\ \ddot{\mathbf{s}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_r \\ \mathbf{Q}_f \\ \mathbf{Q}_a \\ \mathbf{0} \\ \mathbf{Q}_d \end{bmatrix}$$



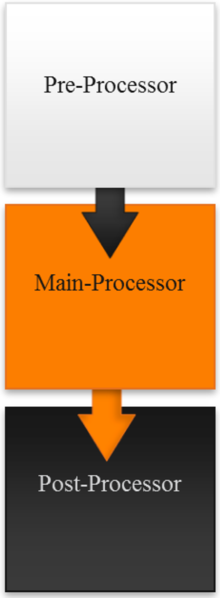


$n_l = 128, \quad n_j = 128$

12,000 non-zero entries

Structure of MBS Software (Post-Processor and Parallelization)

1. The post-processor of the code will provide plotting, graphics, and animation capabilities.
2. It will allow for plotting information from different markers.
3. It will provide the stress and strain distributions within the flexible bodies.
4. Toolkits will be developed in order to allow for the efficient development of complex models.
5. While efficient simulations can now be obtained using a fully sequential code, parallelization can be used to significantly improve the code efficiency.
6. The code parallel architecture can be designed to fully exploit the new HPC capabilities.
7. The structure of the new computer code will be flexible in order to allow interfacing with open source modules. This will allow for the simulation of complex systems using models that have not been implemented in the code.



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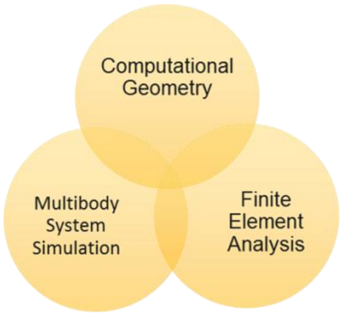
Summary

- MBS software technology is based on formulations developed more than three decades ago.
- The goal of this new TARDEC initiative is to develop a new MBS software technology.
- This will be accomplished by successfully integrating CG/FE/MBS algorithms using ANCF finite elements.
- This integration will solve the costly and time consuming problem of converting solid models to FE meshes.
- It will eliminate the need for three licenses that are now required to perform flexible MBS simulations.
- The new software technology will also allow for systematic and efficient modeling of the large deformation and multi-physics problems.


Computational Geometry
Multibody System Simulation
Finite Element Analysis

THANK YOU!